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ON THE

GRAPHICAL REPRESENTATION

OF THE

MOVEMENTS OF THE CHEST-  
WALL IN RESPIRATION.

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BY

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IN a communication to the Royal Society\* I have given a description of a three-plane stethometer, an instrument for measuring simultaneously the extent of movement of points on the chest-wall in three directions at right angles to one another (namely, forward, upward, and outward) during one act of breathing. Some of the results obtained with this instrument were also given; and in subsequent papers, to the Royal Society and to the Medico-Chirurgical Society†, I have given both the practical applications of the instrument, and the physiological deductions which may be drawn from these measurements.

In these researches, amongst other matters, certain indications were observed which showed that the course described by the end of a rib, in respiratory action, was very far from being regular, and very different from the curve

\* Proc. Roy. Soc. vol. xxi. p. 11.

† Medico-Chirurgical Transactions, vol. lvi. 1873.

which it would produce if its movements were governed simply by the mechanical conditions of the costo-vertebral joints, and by the length and obliquity of the chord-line drawn from its anterior extremity to its head.

In consequence of these indications, it seemed desirable that exact graphical tracings of the course described by the ends of the ribs should be obtained, in order that their peculiarities in different cases might be studied.

The chief difficulty in the way of obtaining these tracings was found in the fact that the course of the movement lay in three planes, instead of in two only.

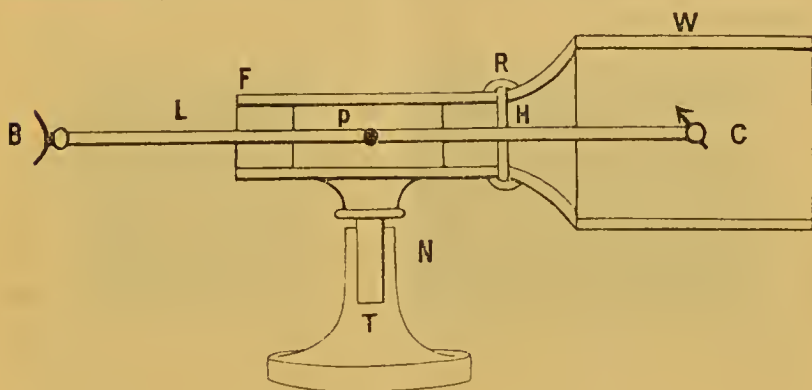
Observations with the three-plane stethometer, however, had shown that the degree of outward or lateral motion possessed by the ends of the ribs was very small, and that the measurements of this movement were of much less importance than those of the other two, which carried with them interesting practical indications.

It seemed better, therefore, to sacrifice the registration of this, the lateral motion, for the sake of bringing the upward and forward movements into the same plane. It was easy to do this by resting the whole apparatus, both the pencil and the ground upon which the course was described, upon a swivel joint, which permitted free rotation with any lateral movement of the chest-wall; and in experiments upon the ends of the ribs this motion is so small, that it produces no perceptible effect upon the movements in the upward and forward direction, and any error that it introduces may safely be neglected.

The stethograph, then, which I have devised consists of a lever (L), 6 inches long, having a pad (B) at one end, connected with it by a ball-and-socket joint, and so shaped as to fit upon the rib, and at the other a finely-pointed pencil (C).

This lever is suspended at its central point by a pivot (P), which permits of free movement up and down, but in

no other direction, and which firmly fixes the lever to a sliding-plate working backwards and forwards in a slot in the frame (F).



A writing-frame (w) is attached to the instrument by a hinge (H); and a spring (R) keeps it continually pressed against the pencil at c. The whole mechanism is then allowed to rotate upon the pivot (N) in the stand (T).

It will be readily seen that these arrangements permit the motion of the pencil (c) backwards and forwards, and upwards and downwards, and that these movements will closely correspond to those of the pad (B), with the difference that the upward movement of the pad will produce a downward thrust of the pencil, and *vice versa*; and thus, when the pad is placed upon the end of a rib, all its movements, with the exception of that directly outward, will be transferred in reverse to the paper or smoked glass contained in the writing-frame; and by having the paper ruled in squares, each one tenth of an inch, the extent of movement in the forward or upward direction can be read off at once.

In using the instrument it is fixed to a table by a clamp, or by a sufficiently heavy weight attached to its foot, and the back of the subject to be examined is firmly supported by a pad placed opposite the costo-vertebral articulation of the ribs whose movements are to be traced. In this

manner any error due to the altered curvature of the spine in respiration is avoided.

It will be observed that the medium for receiving the writing is fixed, so far as its relation to the pen is concerned—that it is not a rotating cylinder, as in Dr. Sanderson's stetho-cardiograph, nor a travelling carrier, as in Dr. Marey's sphygmograph. These devices are needed when a record of the relative force and frequency of the motions is required; but, on the other hand, the introduction of this extraneous movement prevents the accurate delineation of the actual track pursued, in the forward and upward directions, by any point on the chest-wall. By means of the instrument now described, this tracing may be obtained without difficulty.

The following curves are selected in illustration of the results which have been obtained with the stethograph; and, for the sake of affording a simple basis for comparison, they are in the present paper limited, for the most part, to the movements of the ends of the third pair of ribs.

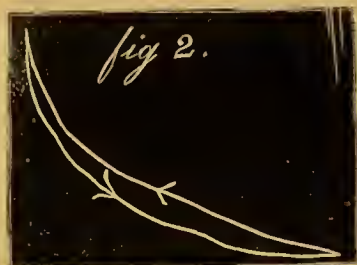
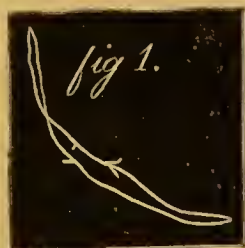
### I. *Movements in Health.*

In observations made with the three-plane stethometer, it had been remarked that the forward motion of the rib was most equable throughout the whole act of respiration, and that in men the upward movement takes place chiefly at the latter portion of the respiratory act, but that in women and children this movement keeps pace with the forward push.

Figs. 1 and 2, from a healthy adult male, and figs. 12, 13, 14, and 15, from a woman and from a youth, entirely bear out this statement. In the tracing No. 2, taken from the right third rib of an adult male, it will be found that the ordinates of the curve in the first half of its course are 0.9 inch of forward to 0.3 inch of upward motion, and in



the latter half they are 0·4 inch forward to 0·75 inch upward. In the female and the youth the curves are much more equable in the two directions of motion.



It may also be noticed in these healthy curves that the lines of the tracing enclose an irregular but yet a perceptible space—in other words, that the anterior end of the rib takes a different course in its ascent from that of its expiratory descent.

In most cases the uppermost line is that of inspiration; and when it reaches its highest point it descends somewhat more abruptly than it rose, being afterwards drawn inwards more horizontally. In other instances, however, this track is reversed, and the descent of the rib is more gradual than its ascent (see figs. 9 and 10); and in some the two tracks will interlace with one another once or twice; or they may occasionally, but very rarely in healthy breathing, follow the same line.

These variations are doubtless produced by the varying degree to which the will interferes with the action. The expiratory act in most persons is at first automatic, and mainly due to the elasticity of the parts; but when a forced effort of expiration has to be made, the voluntary muscles of respiration are used to a greater or less extent according to the will of the subject.

Now it is important to observe that the actual shape of this respiratory curve is very different from what it would

be on the usually received hypothesis, that the ribs are simply rigid bars moving upon the support of their costo-vertebral joints.

It is not difficult to construct the curve which ought to be described by the end of the rib on this hypothesis. The average chord-length of the third rib is known; and the expiratory and inspiratory angles made by the plane of the rib with the vertical can easily be ascertained. Fig. 5 A gives the curve produced with a radius of 6 inches and an initial angle of  $60^{\circ}$ , conditions resembling those of the chest from which figs. 1 and 2 were taken.

Again, another, more direct means of ascertaining the curve formed by the end of the rib in its rise and fall may be taken; and fig. 5 B represents the actual motion of the



fifth rib in a dead male subject, in whom the fourth and fifth intercostal spaces had been divided, and the costo-sternal attachment released, so as to permit of free movement at its vertebral articulation. The rib was then simply raised and depressed, whilst the button of the stethograph rested upon it.

In fig. 5 C some inward pressure was made upon it during its descent, and gradually removed during its ascent.

Now the curve constructed by the simple rise and fall



of the rib considered as a rigid body must necessarily possess the following attributes :—

1. It must approximate to a segment of a circle.
2. It will be the same in its ascent and descent.
3. Its shape for the same rib will always be nearly the same.
4. Its curve will depend (*a*) upon the angle formed by the plane of the rib-circuit with the perpendicular, and (*b*) upon the length of the radius, the chord-length of the rib employed.

It is hardly needful to point out that the first and second of these characteristics are not found in the actual curves described by healthy ribs; and, in order to test the third and fourth, an attempt was made to ascertain what influence could be exerted upon the movement by the constraining power of the will. In figs. 3 and 4 the result is given in



one case (3) of an effort to raise the rib with but little forward motion, and (4) to push its end forward without raising it.

Although the tracing is irregular from the constraint put upon the ordinary motion, it is evident that in No. 3 we have a closer approximation to the simple radial movement; and in No. 4 the effort has succeeded in producing 1·20 inch of forward push with only 0·6 inch of rise.

These peculiarities of the motions of the rib in health

can only be accounted for by an alteration in the chord-length of the rib, due to the action of some constrictor-power possessed by certain of the respiratory muscles.

The tracings of the spasmodic and partly involuntary actions of coughing and sneezing are also interesting, not only from their bearing upon the mechanism by which these acts are accomplished, but also because they afford a strong corroboration of the conclusions drawn from ordinary breathing.

In fig. 6 it may be observed that, after the first rapid



inspiration, which traces an oblique but almost rectilinear line on the paper, there is a momentary depression, as if the rib were commencing to assist in expiration; but this is suddenly stopped by the closure of the glottis, and there is a slight outward bulging of the rib to the extent of 0.05 in. This appearance may probably be explained by the continued action of the diaphragm, which compresses the air in the chest, and so, to some extent, forces the ribs outwards for the moment. Immediately that the air is released from the windpipe, however, there is at once a downward fall of the rib for a space of about 0.2 in., with a barely perceptible incline inwards; there is then a sudden change in the direction of its course, and it is drawn inwards for about 0.4 in. almost horizontally, the fall in this space amounting only to about 0.15 in.

In the first part of the expiratory effort only is there any similarity to the hypothetical curve given in fig. 5.

The second half is entirely unlike any thing that could be radially produced by the rib, and can, in my opinion, only be explained by the bending of the rib, which, as I have shown before, usually occurs in forced expiratory efforts.

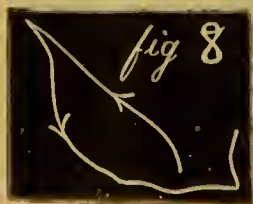
The second act of coughing, which is portrayed in the figure, is almost exactly like the first, except that, as might have been anticipated, there is no slight drop preceding the second sudden closure of the glottis.

In the second figure belonging to the same case (fig. 7),



there are three acts of coughing in the same fit; and it is noticeable that, although the general method by which they are accomplished is the same, the second and third acts are apparently each preceded by a very short inspiratory effort. In all, however, we notice the outward bulge upon the closure of the glottis; and it is very interesting to note that the extent of this forward push became greater the lower the rib descended, as if the rib yielded to the pressure of the air in the chest more easily in the position of partial expiration than in that of full inspiration.

In the act of sneezing, produced by snuff-taking, shown in fig. 8, the course taken by the rib is remarkably like its

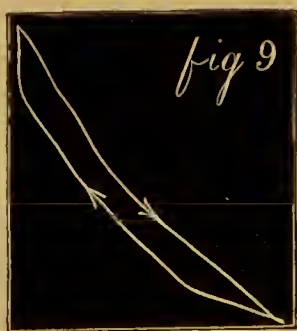


track in coughing. There is first the almost rectilinear

track of quick inspiration, and afterwards the downward drop of the rib, followed immediately by a very strong indrawing of its end. The differences observable are the absence of any stoppage at the commencement of expiration, and the much more complete indrawing in the second half of the expiratory act. The first portion is strikingly similar in its course to the hypothetical curve, its ordinates being about 0.5 in. of downward drop for 0.15 of indrawing; those of the curve given in fig. 5 are 0.8 downwards and 0.2 inwards.

In the second part of its expiratory track the end of the rib only drops about 0.15 in. to 0.8 in. of indrawing, and for six tenths of an inch its course is almost horizontal. I would again repeat that such a movement seems to me impossible without an inbending of the rib.

Figs. 9, 10, and 11 are introduced to show the variations



occasionally produced by individual peculiarities:—first, in

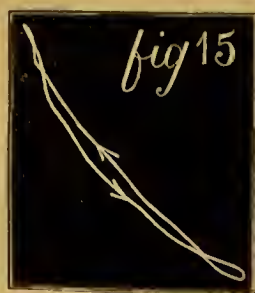
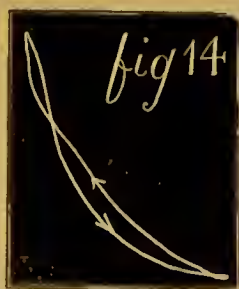
the course of the inspiratory and expiratory tracings; and, second, in the form of the cough-movements, the closure of the glottis taking place after some degree of expiration had been accomplished.

Figs. 12 and 13 display the movements of the third ribs



in a healthy female, æt. 29 years. The pliability of the bones is well shown both by the large extent of forward movement in proportion to the upward rise, and by the variations in the curves of inspiration and expiration.

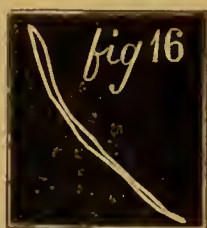
In the boy, æt. 11, from whom the tracings given in figs. 14 and 15 are taken, the same elasticity is apparent,



and the curves also demonstrate the great freedom of movement possessed by the thoracic walls in childhood.

Figs. 16 and 17 mark the differences in the healthy tracing produced by advancing years. There is an approach to the form of curve traced by the unyielding rib;





and the upward and downward track are more nearly alike.

## II. *Movements in Disease.*

A few tracings (figs. 18–28) are given to show the effect of disease upon the form of the respiratory curves:—

Figs. 18, 19, and 20 are from a female, æt. 21, suffering



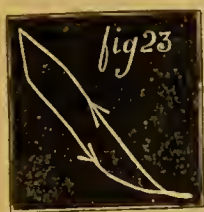
from chronic phthisis on both sides of the chest. Duration 9 years. Fig. 18 is from the least-diseased side, fig. 19 from the third rib over a large contracting vomica. Fig. 20 represents a cough.

Figs. 21 and 22 are from a male, æt. 25, also a case of

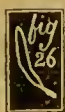


phthisis, but of an acute character, the tracings being taken during an intermission of the disease.

Fig. 23 is from the right third rib, and fig. 24 from the left third rib, in a male subject of chronic phthisis, in whom the left side was chiefly affected. His age was 35, the duration of the disease 4 years.



The four tracings, figs. 25-28, are taken from a female,

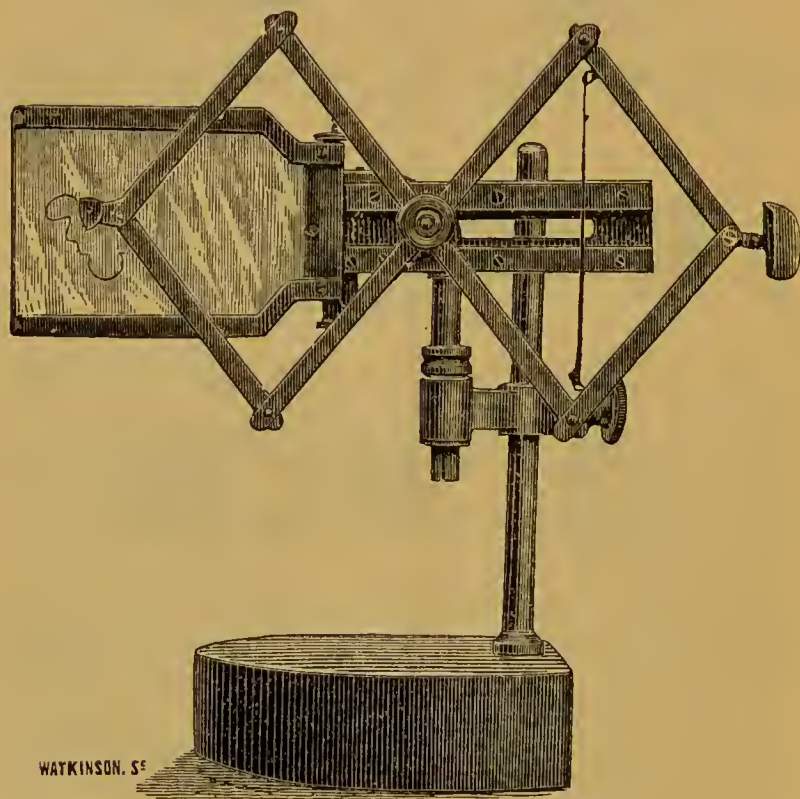


æ. 26, who had acute pleurisy with effusion nine months before, and in whom there was considerable contraction of the left side in consequence. The first two are from the third rib, the last two from the fifth. Figs. 26 and 28 are from the diseased side.

In all these cases the comparative feebleness of the respiratory acts are to be noticed, and the want of elasticity of the chest is evidenced by the tendency to similarity in the upward and downward track of the end of the rib. In the case of acute phthisis there is also a degree of tremulousness in the original tracing; and the ease of pleurisy displays the effect of the subsequent adhesions in the very small extent of the forward push on the affected side. It is interesting to notice that the phthisical cough portrayed in fig. 20 is similar in its form to that of the healthy chest fig. 6, although so much smaller and more feeble.

NOTE.—Since this paper was written, a modification of the instrument has been kindly suggested by Mr. Gibbon, Assistant in the Physiological Laboratory at the Owens College. In order to obviate any risk of error from the

influence of the upward motion of the lever upon the record of the forward push, he proposed to substitute a pentagraphic motion for the sliding-stage (p); and the apparatus, as it is now constructed, presents the appearance shown in the figure.



A large number of observations have been made with this new form of stethograph; but the tracings do not materially differ from those given in the paper, nor do they lead me to alter the descriptions which I have given of the several curves. The alteration of the instrument is an important one, however, and renders the results theoretically more trustworthy.

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